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UCRL-JC-109764
PREPRINT

The ENDF/B-VI Photon Interaction Library

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This paper was prepared for submittal to
the American Nuclear Society Topical Meeting
on "New Horizons in Radiation Protection
and Shielding"
Pasco, Washington, April 26-30, 1992

February 1992

Lawrence Livermore National Laboratory

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Submitted for presentation at the American Nuclear Society Topical Meeting on "New Horizons in Radiation Protection and Shielding" to be held April 26 - 30, 1992, at Pasco, Washington

Work performed under the auspices of the U.S. Department of Energy by the Lawrence Livermore National Laboratory under contract number W-7405-ENG-48.

THE ENDF/B-VI PHOTON INTERACTION LIBRARY

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ABSTRACT

The ENDF/B-VI photon interaction library includes data to describe the interaction of photons with the elements Z=1 to 100 over the energy range 10 eV to 100 MeV. This library has been designed to meet the traditional needs of users to model the interaction and transport of primary photons. However, this library contains additional information which used in a combination with our other data libraries can be used to perform much more detailed calculations, e.g., emission of secondary fluorescence photons. This paper describes both traditional and more detailed uses of this library.

INTRODUCTION

Traditionally the data included in the ENDF/B photon interaction data base has been sufficient to describe the interaction of primary photons with matter. The data traditionally contained in this data base included,

1) Cross Sections: coherent and incoherent scattering, pair production as well as photoelectric absorption

2) Form factors and scattering functions: to describe the angular distribution of coherent and incoherently scattered photons

This data was sufficient to describe the interaction of primary photons with matter. However, it is not adequate to uniquely define the emission of secondary photons following photoelectric effects, e.g., fluorescence. Traditionally it has been assumed that when a photoelectric event occurs all of the energy of the incident photons is deposited at the point of the interaction. In fact in the case of photons with energies near the K photoelectric edge of lead almost 88 % of the energy will be re-radiated as fluorescence x-rays. The traditional data also did not include the effect of anomalous scattering on coherent scattering. Including this effect predicts a coherent scattering cross section which approaches zero at low energy, as opposed to the constant low energy limit predicted by simply using form factors. Lastly the traditional data did not differentiate between pair and triplet production.

Compared to the traditional data included in the ENDF/B photon interaction library, the ENDF/B-VI version contains much more detail; this is the first major extension of the ENDF/B photon interaction library since the inception of ENDF/B.

The new ENDF/B-VI photon interaction library is based on the Livermore Evaluated Photon Data Library (EPDL) [1] and is an extension of earlier libraries since it,

1) Extends the range of elements to cover Z = 1 through 100.

2) Extends the energy range down to 10 eV and up to 100 MeV. Note, EPDL covers the energy range up to 100GeV, but this was truncated to 100 MeV at the request of CSEWG for inclusion in ENDF/B-VI.

3) Includes cross sections for individual photoelectric subshells, pair and triplet production and a coherent cross section including anomalous scattering effects.

4) Includes both form factors and anomalous scattering factors, which can be used in combination to accurately describe the angular distribution of coherently scattered photons.

The increased detail included in this new library can be appreciated by comparing fig. (1), which illustrates cross sections traditionally included in photon interaction interaction libraries and fig. (2), which illustrate photoelectric cross sections for the twenty-four subshells of lead.

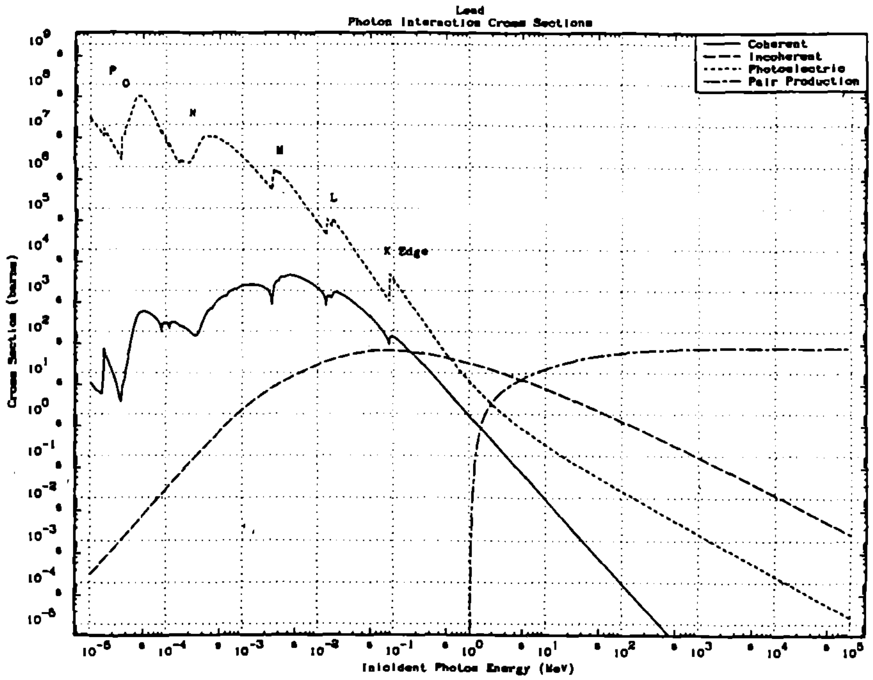

Fig. (1) lead photon interaction cross sections

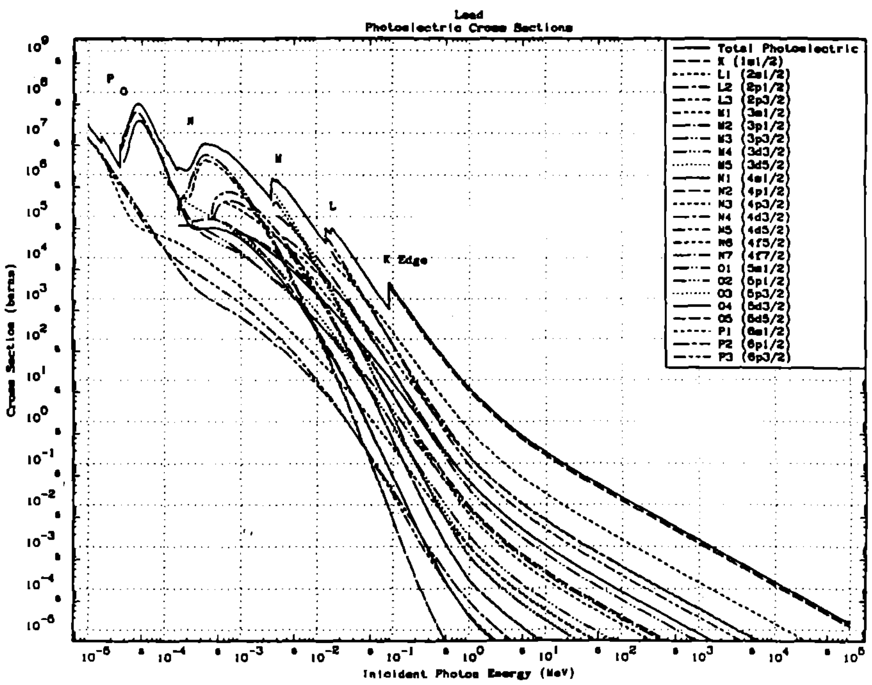

Fig. (2) lead photoelectric cross sections

TRADITIONAL USE

The Livermore Evaluated Photon Data Library (EPDL) from which the ENDF/B-VI library has been derived is documented in ref. [1] and [2]. These reports describe the evaluation methods used to derive this data. Here we will discuss the actual use of the data.

For traditional use to only track primary photons the new library has the advantages that,

1) The cross sections, form facors and scattering functions contained in this library are based on the most recently available experimental and theoretical results.

2) The data covers an extended element and energy range.

3) Even if the anomalous scattering factors are not included in your calculation of the angular distribution of coherently scattered photons, they have already been included in the calculation of the coherent scattering cross section, which should lead to improved computational results.

   This is a major improvement in coherent cross sections. For example, without including the effect of anomalous scattering the coherent scattering cross section for lead at low energy would be predicted approach a constant value of about 4470 barns. In comparison including anomalous scattering predicts a cross section which approaches zero at low energy and from fig. (2) we can see that near 10 eV the coherent cross section is in the range of 1 to 10 barns, rather than 4470 barns.

   For normalized angular distribution of coherently scattered photons one should expect major differences between the results with and without anomalous scattering only below about 1 MeV, and even then only near photoelectric edges. As long as you restrict yourself to these cases you should be able to accurately calculate results without considering the added complication of anomalous scattering.

4) The total energy emitted as fluorescence x-rays is included in the new library. At least to first order this can be used the predict the emission of secondary photons, which can be important in many applications.

MORE DETAILED CALCULATIONS

The Livermore Evaluated Photon Data Library (EPDL), adopted for ENDF/B-VI can be used in combination with two other libraries to perform more detailed calculations. These other libraries are,

2) The Evaluated Electron Data Library (EEDL), which describes the interaction of electrons with matter.

   Fig. (3) illustrates the lead electron ionization subshell sections.

3) The Evaluated Atomic Data Library (EADL), which describes the emission of x-rays and electrons as an atom relaxed back to neutrality following an ionization event.

   Fig. (4) illustrates the x-ray spectrum emitted following a single ionization of the lead K shell. The points represent discrete energies of the x-rays emitted and the continuous line represents the integral of the emitted energy.

For compatibility all three libraries cover the same elements, Z = 1 to 100, and energy range, 10 eV to 100 GeV, and use exactly the same atomic parameters throughout, e.g., all use the same subshell electron binding energies.

Used in combination these three libraries can be used to completely describe coupled photon-electron transport. All photon induced electron production through pair, incoherent scattering, primary electrons from photoionization, as well as secondary electrons from atomic relaxation can be accounted for. Similarly all electron induced photon production through positron annihilation, bremsstrahlung, as well as secondary photons from atomic relaxation can be accounted for.

As yet the ENDF/B formats and conventions only allow the photon interaction library to be made available in the ENDF/B format. This library is currently internationally available for use and is documented in refs. [1] and [2].

Currently all three of these libraries are only available in the Livermore ENDL format. However discussions are underway to extend the ENDF/B formats and conventions to handle electron interaction and atomic relaxation. So that hopefully in the not too distant future all of this data will be available in the ENDF/B format.

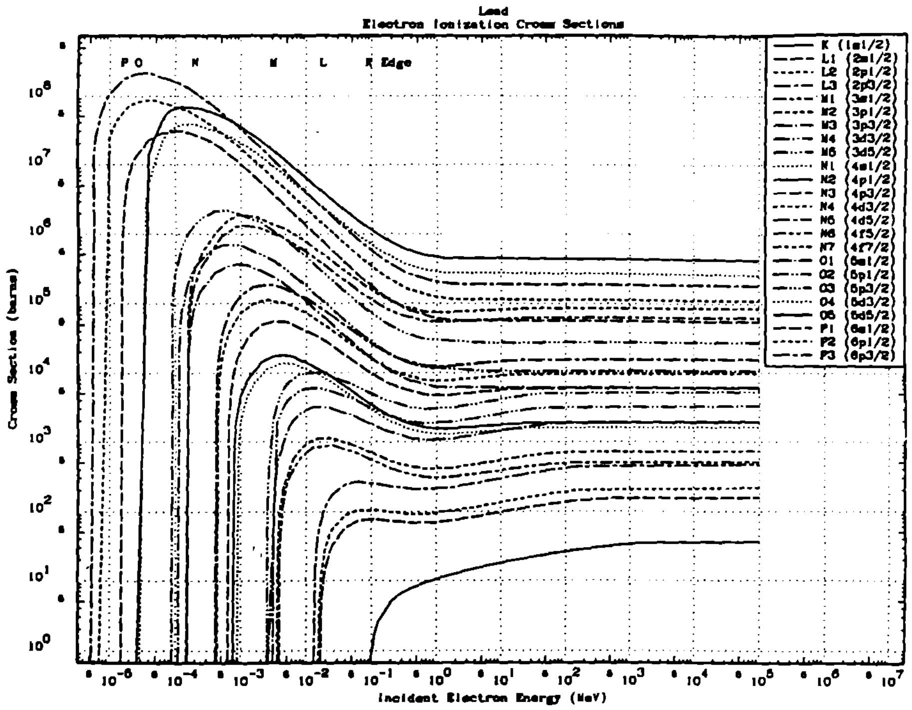

Fig. (3) lead electron ionization cross sections

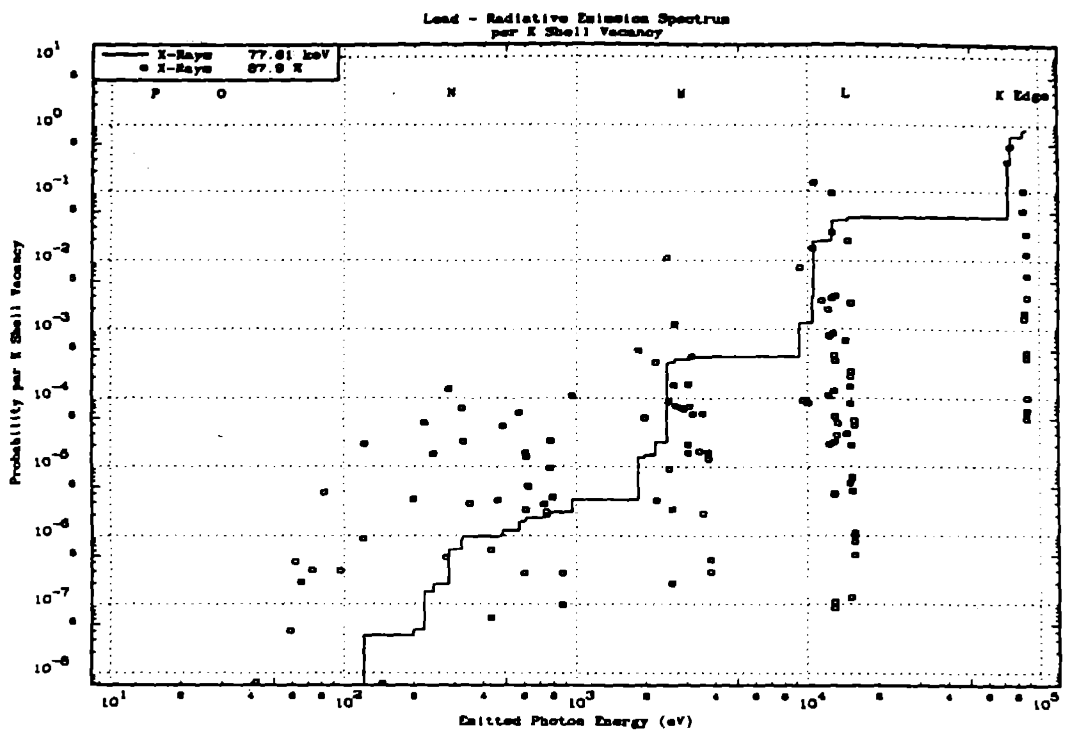

Fig. (4) lead K shell radiative emission spectrum

TRADITIONAL VS. DETAILED CALCULATIONS

The question of when traditional or detailed calculations are adequate or required for any given application depends very much on the size scale of interest. Compared to the traditional method, detailed calculations including electron transport can be quite expensive. Generally we cannot afford to naively assume that we must perform detailed calculations for all applications. However, if we expect to obtain accurate answers we also cannot naively assume that traditional methods will provide the accuracy that we require for all applications. We must try to obtain a balance to apply the traditional or detailed calculations where each can provide accurate answers at a reasonable cost.

It should be remembered that there are no processes which allow a photon to directly transfer its energy to an atom. In all cases photons can only directly transfer energy to electrons. The electrons will then transport and deposit their energy in a medium. The distant that electrons transport depends on their initial energy (higher energy electrons will transport further) and the material they transport through (they will transport further in low Z materials then they will in high Z materials).

Therefore the question of whether or not the traditional method of assuming that the energy of a photon is deposited at the point of an interaction depends on how far the electrons generated will transport. For a given application if these distances are small compared to some characteristic size of interest the traditional method should be adequate to produce accurate answers.

For most reactor calculations where one is dealing with large volumes of material the traditional method should be more than adequate to produce accurate answers within these large volumes.

However, there are also many applications where detailed calculations must be used if one expects to obtain realistic answers. For example, in medical applications one should not expect to be able to use the traditional method to define the image which appear on a thin x-ray film; in this case results can be dominated by the transport of electrons into, out of and within the film. Here the size scale is too small to allow the traditional method to be used. Similarly there are industrial applications, where the answers are extremely sensitive to the distribution of energy deposited by electrons, as in the production of micro chips for computers, or for that matter the deposition of energy or charge in electronic equipment (including that used to control nuclear reactors), or in high Z materials, where the high production of electrons in the high Z material can lead to large numbers of electrons leaking into the low Z material and there they transport rather large distances.

No general recommendation can made that will meet all needs concerning the choice of either traditional or detailed calculations. Here we merely wish to bring to people's attention the fact that the traditional assumption concerning energy deposition at a point breaks down when one requires more and more spatial details in the answer.

CONCLUSION

The ENDF/B-VI photon interaction library includes data to describe the interaction of photons with the elements Z=1 to 100 over the energy range 10 eV to 100 MeV. This library has been designed to meet the traditional needs of users to model the interaction and transport of primary photons. However, this library contains additional information which used in a combination with our other data libraries can be used to perform much more detailed calculations, e.g., emission of secondary fluorescence photons.

For now the new ENDF/B-VI photon interaction should provide improved traditional results due to inclusion of the latest experimental and theoretical data during the evaluation process. Since this library was expanded to contain more elements, over a wider energy range, there are more applications that can now be considered.

For the future if both electron interaction and atomic relaxation data are included within ENDF/B this should allow ENDF/B to be extended to perform detailed calculations in many industrial and medical applications.

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